

TRIM ZENER USING DOUBLE POLY PROCESS

Field of the Invention

The accuracy of analog integrated circuits is typically limited by the amount of control one has during the fabrication process over the absolute value and matching tolerances of the integrated devices. This is particularly true in the case of mixed signal VLSI in which both digital and analog circuits are present, but the yield is largely limited by the analog circuit. Furthermore, in mixed signal integrated circuits, the digital circuits determine most of the size of the device, thus the failure of a small analog section of a chip has drastic implications on the yield of the mixed signal design.

Trimming techniques have been developed to improve the accuracy and yield of integrated circuits. Trimming refers to the making of adjustments to the integrated circuit after its fabrication is complete.

One trimming method is the use of anti-fuse approach applicable to both bipolar and CMOS designs. The term anti-fuse is used to describe an element which initially appears as an open-circuit but can be made to approach a short circuit by forcing conduction of a high-current for a short duration of time. Anti-fuse devices have been created in integrated circuits by various methods. One of the method creates anti-fuse devices by forcing a temporary avalanche breakdown in a p-n junction, sufficient to cause localized heating and subsequent migration of metal across the junction. This method of creating an anti-fuse is commonly referred to as zener zap.

Figure 1 shows a typical application of zener zap diodes to achieve resistor trimming. Diodes 10 are connected in parallel with resistors 12 wherein each of the resistors 12 is made small compared to the total resistance of the resistor string. Pads 14 allow each of the individual zener zap diodes 10 to be contacted to apply the requisite current to convert the effective open circuit of the diode 10 to a short circuit. Commonly, zener zap diodes are created as illustrated in Figure 2, with the cathode of the diode created as a circular diffusion with a contact 20. The cathode is typically heavily doped n-material, which may be 1-3 microns deep with sheet resistance of 5-10 Ohms per square. In contrast, the anode 22 is created by a moderately doped p-diffusion, for example, 3-5 microns deep with sheet resistance of 100-200 Ohms per

square. The metal interconnect 24 of the anode 22 presents a flat surface to the contact of the cathode 20. In this embodiment, the n⁺-diffusion is placed inside the p-diffusion as in a conventional bipolar transistor device. This is also illustrated in a cross-section in Figure 3 showing the cathode 20 in the anode 22. It will, however, be appreciated that other configurations may be used such as the one illustrated in Figure 4. In this embodiment, the cathode 40 forms only a small overlap with the p diffusion of the anode 42.

It has been shown that for a diode doped as discussed with reference to Figures 2 and 3, where the n-material is heavily doped and the p-diffusion is only moderately doped, the p-material doping will determine the junction breakdown. The higher the doping of the p-material, the lower the breakdown voltage. Furthermore, since most fabrication processing creates a doping profile that results in maximum density at the surface of the doped material, the voltage breakdown typically occurs at the surface of the vertical p-n junction.

At breakdown, power is dissipated in the junction as given by the equation

$$P = BV.I$$

where I is the current conducted through the junction during breakdown, BV is the breakdown voltage, and P is the power dissipated in the junction. If no limited is placed on current I, the junction will heat rapidly and can destroy a number of mechanisms. On the other hand, if current I is limited, the power P will cause localized heating around the area where the current is concentrated. If current I is applied for a fixed time, sufficient heating can occur to cause migration of atoms of the metal interconnection from the cathode terminal to the anode terminal of the diode along the path of the breakdown current. This migration of metal establishes a trace of metal, typically aluminum, embedded in the silicon along the path of the current, near the surface. This electro migration of aluminum comprises two phases. During the first phase an initial breakdown and heating occurs during which the metal interconnect atoms are mobilized and begin to flow across the junction. The second phase involves the carrying of a sufficient number of the metal atoms to create a low resistance path through the silicon. One approach found to work well is to initiate the first phase with a high peak current of short duration, followed by a lower current of longer duration. For example, a current of 100-200 mA may be applied for 0.5-1 milliseconds followed

by a current of 30-60 mA for a period of 2-3 milliseconds. Once the metal has migrated and created a current path, the zener zap diode is essentially short circuited. Thus, in a cascaded resistor network as illustrated in Figure 1, the zener zap diodes 10 can be selectively short circuited by applying the appropriate high current to the pads

5 14.

As integrated circuits become ever smaller and bearing in mind the risk of electrostatic discharge (ESD) currents, the aluminum contacts pose the risk of unwanted migrations taking place in certain integrated circuit devices. As a result, aluminum contacts have been isolated from the silicon using tungsten plugs. By introducing the creation of tungsten plugs in the process, the migration of aluminum in zener zap diodes is, however, also prevented. What is needed is a way of producing a zener zap anti-fuse while dealing with the fact that the aluminum needs to be isolated from the silicon, for example, by the use of tungsten plugs.

15 Summary of the Invention

The present invention provides a method and an architecture for forming a zener zap anti-fuse using a double poly process.

According to the invention, a bipolar junction is created involving a n doped region and a p doped region that are in contact with a refractory metal such as cobalt which is reacted with the silicon to form a silicide metal. The metal silicide, for example cobalt silicide, is caused to migrate across the bipolar junction to form a low resistance current path between contacts to the n doped and p doped polysilicon regions.

The present invention seeks to make use of the normal double poly process steps and avoid the introduction of additional steps in forming the zener zap diode.

According to the invention, there is provided a zener zap diode device comprising a p-doped region formed in a tub, a n-doped region that is spaced from the p-doped region, thereby defining a p-n junction between the p-doped region and the tub or between the n-doped region and the tub depending on the doping of the tub, and a refractory metal silicide extending over part of at least the p-doped region, wherein the configuration of the device is such that the refractory metal silicide will form a silicide bridge across the p-n junction when a fusing current is established across the junction.

- The diode device of further includes a highly doped region in the tub which has the same polarity as the tub and extends partly between the p-doped and n-doped regions without shorting out the p-n junction. One typical refractory metal silicide is Cobalt silicide. Typically, the silicide bridge is formed to extend between the silicide on the p-doped region and silicide on the n-doped region or, if there is no silicide on the n-doped region, to a contact of the n-doped region. The p-doped region may be formed by a p-doped polysilicon layer and the n-doped region may be formed by a n-doped polysilicon layer, and the p-doped polysilicon layer and n-doped polysilicon layer may be part of two different polysilicon layers in a multi-poly process, or part of the same polysilicon layer in a multi-poly process. The invention envisages that the configuration of the device is such that the distance across which the bridge has to be formed is sufficiently short and the resistance path across which the bridge has to be formed is sufficiently low so as to allow the fusing current to be sufficiently low to avoid undesirable damage to the device when the fusing current is established across the junction. The p-doped region may be formed by a p-doped polysilicon layer and the n-doped region may be formed by a n-doped polysilicon layer, wherein said n-doped polysilicon layer and p-doped polysilicon layer are spaced from each other by at least a nitride spacer.

- Further, according to the invention, there is provided a zener zap diode device comprising a p-doped region formed in a tub, a n-doped region that is spaced from the p-doped region, thereby defining a p-n junction between the p-doped region and the tub or between the n-doped region and the tub depending on the doping of the tub, and a refractory metal silicide extending across the junction.

- Still further, according to the invention, there is provided a zener zap diode device, comprising a p-n junction between a p-type material and a n-type material, a refractory metal silicide over at least the p-type material, an electric contact to the refractory metal silicide over the p-type material, an electric contact to the n-type material, and a highly doped region of the same polarity as the p-type material or n-type material extends at least partially through the p-type or n-type material to provide a lower resistance current path without shorting out the p-n junction, wherein the configuration of the device is such that the refractory metal silicide will form a silicide bridge across the p-n junction when a fusing current is established across the junction.

Typically, the electric contact to the n-type material contacts the n-type material through at least a refractory metal silicide, and the highly doped region is typically formed in an epitaxial region or sinker region which forms the n-type or p-type region.

- Still further, according to the invention, there is provided a zener zap diode
- 5 device, comprising a first region of a first polarity in a tub of opposite polarity to define a p-n junction, a second region with the same polarity as the tub, spaced from the first region, and refractory metal silicide material in electrical contact with the first and second regions, wherein the configuration of the device is such that the refractory metal silicide will form a silicide bridge across the p-n junction when a fusing current
 - 10 is established across the junction. Preferably, a highly doped region of the same polarity as the tub extends partially between the first region and the second region without shorting out the p-n junction. The tub may be an epitaxial region or sinker region. The highly doped region extending partially between the first and second regions may be formed by a first poly layer in a double poly process, and the first and
 - 15 second regions may be formed by a second poly layer in a double poly process, or vice versa. The first and second regions may, instead, be formed by two different poly layers in a double poly process.

- Still further, according to the invention, there is provided a method of forming a zener zap diode device comprising forming a first polysilicon layer on an n-type silicon
- 20 material, n-doping the first polysilicon layer, forming a second polysilicon layer on the n-type silicon material to lie substantially on either side of the first layer, n-doping a first portion of the second poly silicon layer, p-doping a second portion of the second polysilicon layer, depositing a refractory metal layer on at least the second polysilicon layer, reacting the refractory metal with silicon of the second polysilicon layer to form
 - 25 a silicide, and establishing a current between the first and second portions of the second polysilicon layer to establish a silicide bridge made from the refractory metal silicide to provide a low resistance path between contacts to the first and second portions, wherein the first and second polysilicon layers are formed in any order and the doping is performed at any stage that is appropriate in the process. The refractory metal may
 - 30 be Cobalt and the silicide bridge comprise a Cobalt silicide bridge. The polarities of the structures and dopants could instead be opposite to those described above.

Still further, according to the invention, there is provided a method of forming a zener zap diode device, comprising forming a first polysilicon layer on a n-type silicon, n-doping the first polysilicon layer, forming a second polysilicon layer on the n-type silicon, spaced from the first polysilicon layer, p-doping the second polysilicon layer, depositing a refractory metal layer on at least part of the second polysilicon layer, reacting the refractory metal with silicon to form a silicide, and establishing a current between the first and second polysilicon layers to create a silicided bridge formed from the metal silicide to form a low resistance path between contacts to the first and second polysilicon layers, wherein the steps are performed in an order suitable for a double poly process. Again, the polarities of the structures and dopants could instead be opposite to those described above.

Brief Description of the Drawings

- Figure 1 is a schematic circuit diagram of a cascaded set of trim elements;
- Figure 2 is a plan view of one embodiment of a zener zap device of the prior art;
- Figure 3 is a sectional view of the device of Figure 2;
- Figure 4 is another prior art embodiment of a zener zap device shown in plan view;
- Figure 5 shows a sectional view of one embodiment of a trim zener of the invention;
- Figure 6 shows a sectional view of another embodiment of a trim zener of the invention, and
- Figure 7 shows a sectional view of yet another embodiment of a trim zener of the invention.

Detailed Description of the Invention

- Figure 5 shows a device comprising a n-buried layer (NBL) 50 formed in a substrate. Two polysilicon layers are formed in a n-epitaxial or n+ sinker region 52 in creating the device: a first poly layer 54, and a second poly layer 56. In this embodiment, the first poly layer 54 is formed first and is therefore depicted as poly 1, while the second poly layer is formed after the first poly layer 54 and is therefore

depicted as poly 2. The second poly layer 56 is n-doped to form a n⁺ emitter 58 in the n-epitaxial or n⁺ sinker region. The first poly layer 54 comprises two portions which are oppositely doped in this embodiment. A first portion 62 of the first polysilicon layer 54 is p-doped to form a p-extrinsic base (PXB) 64 in the n-epitaxial region or n⁺ sinker 52. A second portion 68 of the first polysilicon layer 54 is n-doped to define a n-extrinsic base (NXB) 70 in the n-epitaxial or n⁺ sinker region 52. A p-n junction is established in this embodiment by the PXB region 64 and the n-epitaxial or n-sinker region 52 which is contacted through the NXB region 70 and the n-doped poly 1 portion 68.

Figure 5, further shows a silicided refractory metal layer 80 which, in this case, is a Cobalt silicide layer. In practice, Cobalt or other refractory metal is blanket deposited on the device and thereafter reacted at elevated temperatures with the silicon to form the silicide. The unreacted Cobalt or other refractory metal is then etched off leaving only the areas of Cobalt silicide on the polysilicon areas. The silicide at this point in the process is often referred to as salicide. As can be seen in Figure 5, the Cobalt silicide layer is formed on top of the first and second polysilicon layers but does not extend over the oxide dielectric 82. In this way the bipolar junction is maintained. As can be seen, the regions 62 and 68 are isolated from the second polysilicon region 56 by the nitride spacers 84. However, a lower resistance path is created by the n-emitter 58. Thus when the device is reverse biased by applying a voltage across the contacts 90, which in this embodiment comprise aluminum contacts formed in titanium nitride (TiN) sleeves 94, a fusing current is established which heats the junction and causes the Cobalt silicide to migrate across the junction to form a silicide bridge, in this case a Cobalt silicide bridge. Thus, by using standard process steps in a double poly process and configuring the spacing of the bipolar junction and modifying the resistance path across the junction, Cobalt or another refractory metal can be used to establish a silicide bridge across the junction thereby effectively shorting out the junction. Thus, the present invention allows the device to be used as a zener zap diode.

Another embodiment of the invention is illustrated in Figure 6 showing a device comprising a n-buried layer (NBL) 50 formed in a substrate. Two polysilicon layers are formed in a n-epitaxial or n⁺ sinker region 114 in creating the device. The first polysilicon layer (poly 1) 100 is used to form a n-extrinsic base (NXB) 102. The

second polysilicon layer (poly 2) 104 includes a p-doped portion 106 and a n-doped portion 108. The two polysilicon regions 106, 108 form a p⁺ region 110 and a n⁺ region 112, respectively, in a n-epitaxial region or n-sinker region 114. The p⁺ region 110 and n⁺ region 112 define either emitters, in the case of bipolar devices, or the drains and sources in the case of MOS devices. A p-n junction is established in this embodiment by the p⁺ region 110 and the n-epitaxial or n-sinker region 114 which is contacted through the n⁺ region 112 and the n-doped poly 2 portion 108. Again, the poly 2 portions 106, 108 are spaced from the poly 1 layer 100 by means of nitride spacers 120. The Cobalt silicide or other silicided refractory metal 122 extends across the first and second poly layers 100, 104 but maintains the bipolar junction by virtue of the oxide dielectric 124. Again, a silicide bridge can be established across the junction by migrating the Cobalt silicide atoms across the p-n junction from the p-doped poly 2 portion 106 to the n-doped poly 2 portion 108.

Figure 7 shows yet another embodiment of the invention. A n-tub in the form of a n-epitaxial region or n-sinker region 250 is bounded on its lower surface by a n-buried layer (NBL) 252 and on its sides by oxide regions 254. In this embodiment the first formed polysilicon layer (poly 1) 260 is n-doped to define a n-extrinsic base (NXB) 262 in the tub 250. The second formed polysilicon layer 264 is p-doped to form a p⁺ region 266 in the tub 250. The p⁺ region could be an emitter, in the case of a bipolar device, or a source or drain in the case of a MOS device. The second formed polysilicon layer 264 (poly 2) is spaced from the poly 1 region 260 by a nitride spacer 270, to define a p-n junction between the p⁺ region 266 and the n-epitaxial or n-sinker region 250 which is contacted through the NXB 262 and n-doped poly 1 layer 260. A Cobalt silicide layer 274 or other silicided refractory metal is formed on top of the polysilicon layers 264, 260. Again an oxide region, in this case oxide region 280, prevents the Cobalt silicide shorting out the p-n junction prematurely. Again, this device can be used as an anti-fuse in accordance with the invention by selectively shorting out the p-n junction by applying a reverse voltage across the p-n junction to cause electron flow from the p⁺ polysilicon region 264 to the n⁺ polysilicon region 260 thereby causing Cobalt silicide atoms to migrate across the junction to form a Cobalt silicide bridge that shorts out the p-n junction. It will be appreciated that the Cobalt silicide layer need only be formed on the p⁺ polysilicon region 264, however, a

typical process will usually form the Cobalt silicide on both polysilicon layers 264, 260. This also has the advantage that the silicide bridge need only extend from the cobalt silicide layer on the p- polysilicon region to the cobalt silicide layer on the n+ polysilicon region instead of all the way to the actual contact. Thus the length of the bridge is reduced, which is one of the considerations of the invention in providing a configuration that will allow a bridge to be formed under sufficiently low zap currents so as to avoid unwanted damage to the structure.

While the embodiment of Figure 5 referred specifically to a bipolar process, the present invention is equally applicable to CMOS processes. It will further be appreciated that in each case a p-n junction exists that creates the diode in each of the various embodiments.

In the embodiment of Figure 5, the contacts were aluminum contacts in a titanium nitride (TiN) sleeve. It will be appreciated, however, that other contacts can be formed. For example, tungsten plugs connected to aluminum contacts can be formed by depositing a dielectric, etching windows into the dielectric, depositing a plug liner, growing tungsten plugs in the windows, appropriately etching back, depositing a metal slab, and appropriately masking and etching the metal layer.

Also, n-buried layers were shown in the examples of Figures 5-7. The invention could, however, also be implemented with a p-buried layer depending substrate used. Thus, while specific examples were discussed above, it will be appreciated that the present invention can be implemented with different devices by reversing the doping type. More generally, while specific examples were discussed above, it will be appreciated that the present invention can be implemented in a variety of ways without departing from the scope of the claims. Even in the case of multiple polysilicon layer processes, various configurations of the present invention can be devised without departing from the scope of the claims. Portions of the same or different polysilicon layers can be appropriately doped to define the contact regions to the p-n junction, and the device can be configured so as to facilitate the formation of a silicide bridge that is sufficiently short so that under zap currents the current does not otherwise damage the zener zap diode other than selectively shorting the device across the p-n junction by establishing the silicide bridge. This appropriate configuration of the structure is achieved by appropriately positioning the elements across which the

bridge has to be formed and, when necessary, establishing a lower resistance path in the tub by establishing a highly doped region in the tub having the same polarity as the tub, e.g. a n⁺ region in a n-tub or a p⁺ region in a p-tub, wherein the highly doped region extends partially across the tub while avoiding shorting out the p-n junction.

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